

The Daya Bay Reactor Neutrino Experiment

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Abstract. The Daya Bay reactor neutrino experiment is designed to study the disappearance of antineutrinos from the Daya Bay nuclear power plant in China. The goal of this experiment is to measure the remaining unknown neutrino mixing parameter θ_{13} with high precision: $\sin^2(2\theta_{13}) < 0.01$. The experiment is presently under construction and it is anticipated that data acquisition will begin in 2011.

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During the last decade we have obtained convincing experimental evidence for neutrino oscillations that indicates strong flavor mixing and very light (compared to the charged fermions), but finite masses [1]. The strong mixing is associated with the second mass eigenstate (m_2), as indicated by the experimental values of the mixing angles [2, 3]

$$\tan^2 \theta_{12} = 0.47^{+0.06}_{-0.05} \quad (1)$$

$$\sin^2 2\theta_{23} > 0.92 \quad (2)$$

corresponding to central values of $\theta_{12} = 34^\circ$ and $\theta_{23} = 45^\circ$. However, the third mixing angle θ_{13} is apparently smaller [4]

$$\sin^2 2\theta_{13} < 0.19 \quad (90\% \text{ CL}) \quad (3)$$

and recent global fits [5] to reactor neutrino data (including CHOOZ, KamLAND, and Palo Verde) and solar neutrino data (assuming CPT invariance) indicate even smaller values for θ_{13} . The mixing of the neutrino eigenstates is described by a 3×3 unitary matrix [6, 7] that depends on the 3 mixing angles (θ_{12} , θ_{23} , and θ_{13}) plus a CP -violating phase δ_{CP} . It is important to note that the matrix element involving the CP -violating phase, $\sin \theta_{13} e^{-i\delta_{CP}}$, vanishes if $\theta_{13} = 0$. Thus the angle θ_{13} can be viewed as the gateway to observation of CP violation in the lepton sector and there is great current interest in measuring the value of this angle.

The formula for survival of electron neutrinos (or antineutrinos) in the 3 flavor case is given by [8]

$$P(\nu_e \rightarrow \nu_e) \cong 1 - \sin^2 2\theta_{13} \sin^2 \Delta_{31} - \cos^4 \theta_{13} \sin^2 2\theta_{12} \sin^2 \Delta_{12} \quad (4)$$

where $\Delta_{ij} \equiv \Delta m_{ij}^2 L / 4E_\nu$. Note that the 2 terms oscillate with different “frequencies” depending on the values of the Δm_{ij}^2 . Thus one can choose the baseline L to maximize (or

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minimize) the sensitivity to particular Δm_{ij}^2 . For an average reactor antineutrino energy of 4 MeV and a value of $\Delta m_{32}^2 = (2.43 \pm 0.13) \times 10^{-3} \text{ eV}^2$ one finds that the optimum distance for the first minimum is $L \simeq 2000 \text{ m}$.

DAYA BAY EXPERIMENT

The Daya Bay reactor neutrino experiment [9] is being constructed by a large collaboration from Asia, North America, and Europe at the Daya Bay nuclear power plant in southeast China (near Shenzhen and Hong Kong). The power plant presently has 4 reactor cores in operation, with 2 more under construction to begin operation in 2011, when the total thermal power will reach 17.4 GW. The reactor site is located adjacent to mountainous terrain composed of granitic rock that is very suitable for tunneling to establish underground detector facilities with substantial overburden to reduce cosmic ray backgrounds. The experimental layout is shown in Fig. 1.

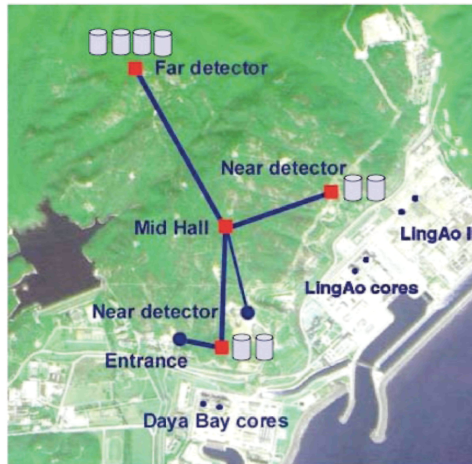


FIGURE 1. Configuration of the Daya Bay experiment. The reactors are located in 2 groups with a pair at the “Daya Bay” location and the remaining at the “Ling Ao” location, about 1 km distance from the “Daya Bay” cores.. Four detector modules are deployed at the far site and two each at each of the near sites.

The Daya Bay experiment will utilize eight identical detector modules, each with a target mass of 20 Tonnes. These detectors will be deployed in three experimental halls, connected by horizontal tunnels, as shown in Fig. 1. Each experimental hall contains a water pool in which the detector modules are immersed. The 2.5 m of water surrounding the detectors provides shielding from radioactivity in the rock walls. In addition, the water will be instrumented with photomultiplier tubes to identify cosmic ray muons. A set of resistive plate chambers over the water pool provides additional redundancy to the muon veto, to achieve the design goal of 99.5% efficiency.

The detector module design is shown in Fig. 2. The cylindrical detector target consists of 20 Tonnes of Gd-loaded liquid scintillator enclosed in a 3.1 m diameter acrylic vessel.

The scintillator is linear alkyl benzene (LAB) doped with 0.1% Gd plus PPO and bis-MSB as wavelength shifters. The target region is surrounded by a liquid scintillator gamma catcher (to improve the efficiency for detection of the neutron capture on Gd) contained in a 4 m acrylic vessel. A mineral oil buffer outside the gamma catcher region reduces background from the 192 8-inch photomultipliers and the 5 m diameter stainless steel tank. Reflective sheets increase the light collection to obtain energy resolution of $\sim 12\%/\sqrt{E(\text{MeV})}$. There are three automated calibration units mounted on top of each detector to enable deployment of calibration sources along 3 vertical axes (central, inside the acrylic wall, and in the gamma catcher). Each calibration unit can deploy an LED ball, a ^{76}Ge positron annihilation source, and a combination $^{60}\text{Co}/\text{Am-C}$ gamma/neutron source through flexible teflon tubes penetrating into the detector regions.

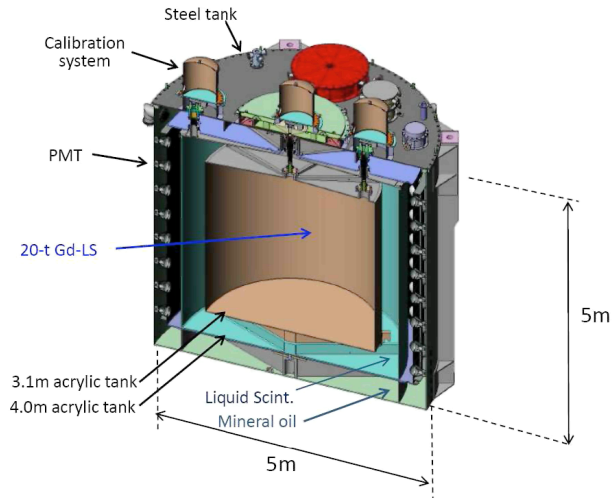


FIGURE 2. Cross-sectional view of the Daya Bay detector module, showing the three regions for the Gd-LS (center), gamma catcher, and buffer oil (outer).

In addition to the comprehensive calibration program, control of detector-related systematic errors will be facilitated by a precisely reproducible filling procedure. After assembly in the surface facility above ground, pairs of empty detector modules will be moved underground to the filling hall. This underground facility will be capable of filling the three regions of liquid simultaneously, with precise measurement (with load cells and flow meters) of the mass of liquid transferred to the central target region. The detector pairs will be filled in succession (to insure that the scintillator properties are identical) and then deployed, one to a near hall and one to a far hall, to facilitate cancellation of systematic errors. The resulting uncorrelated detector related systematic uncertainty will be less than 0.38% per module.

SCHEDULE AND PROJECTED SENSITIVITY

The projected sensitivity is shown in Fig. 3 for three years of running. At the value of $\Delta m_{13}^2 = 2.5 \times 10^{-3} \text{ eV}^2$, the sensitivity is $\sin^2 2\theta_{13} < 0.008$ (90% CL). We expect to have 2 detectors operating at the Daya Bay near hall for a commissioning run in summer 2010. The installation of experimental equipment is expected to be completed in summer 2011 when we should be ready to begin acquiring data.

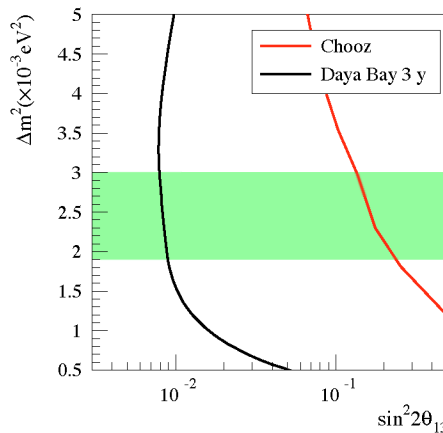


FIGURE 3. Expected $\sin^2 2\theta_{13}$ sensitivity at 90% C.L. with 3 years of data, as shown in solid black line. The red line shows the current upper limit measured by Chooz, and the green band indicates the allowed region of Δm_{13}^2 .

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